Applicability of NASA Polar Technologies to British Antarctic Survey Halley VI Research Station

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From 1993 through 1997 NASA and the National Science Foundation (NSF), developed a variety of environmental infrastructure technologies for use at the Amundsen-Scott South Pole Station. The objective of this program was to reduce the cost of operating the South Pole Station, reduce the environmental impact of the Station, and to increase the quality of life for Station inhabitants. The result of this program was the development of a set of sustainability technologies designed specifically for Polar applications. In the intervening eight years many of the technologies developed through this program have been commercialized and tested in extreme environments and are now available for use throughout Antarctica and circumpolar north. The objective of this document is to provide information covering technologies that might also be applicable to the British Antarctic Survey's (BAS) proposed new Halley VI Research Station. All technologies described are commercially available.

The NASA South Pole system was designed to provide an integrated wind/diesel power system; liquid waste treatment, solid waste treatment, and food production technologies. A 100 kW wind turbine was developed and tested. A smaller 3 kW version is also available. Both turbines can be integrated with diesel generator sets through the Village Power System. This combination allows for high turbine penetration in small, isolated, and potentially unstable electrical grids. Both the turbines and the village power system are now commercially available and installations exist around the World. Turbine snow/ice foundation technologies were also developed and tested at the South Pole.

Water treatment was completed using the Wiped-Film Rotating-Disk (WFRD) evaporator. This system can operate on electrical or low-grade waste thermal energy. It also provides a level of resistance to solids fouling that make it uniquely capable of treating high solids sewage from water rationed applications. This technology eventually evolved into the bases for NASA's next generation spacecraft water recycling system and is currently the NASA baseline for a Mars transit vehicle. Solid waste treatment was completed using the Steam Reformation technology. This technology was designed specifically to address the Antarctic Treaty restrictions on incineration of wastes. This technology went on to become the basis for a system currently used to destroy solid wastes generated during the decommissioning of nuclear power plants and research facilities. A mass flow diagram of the NASA waste system is provided in Figure 1 (wind/diesel system is not shown)

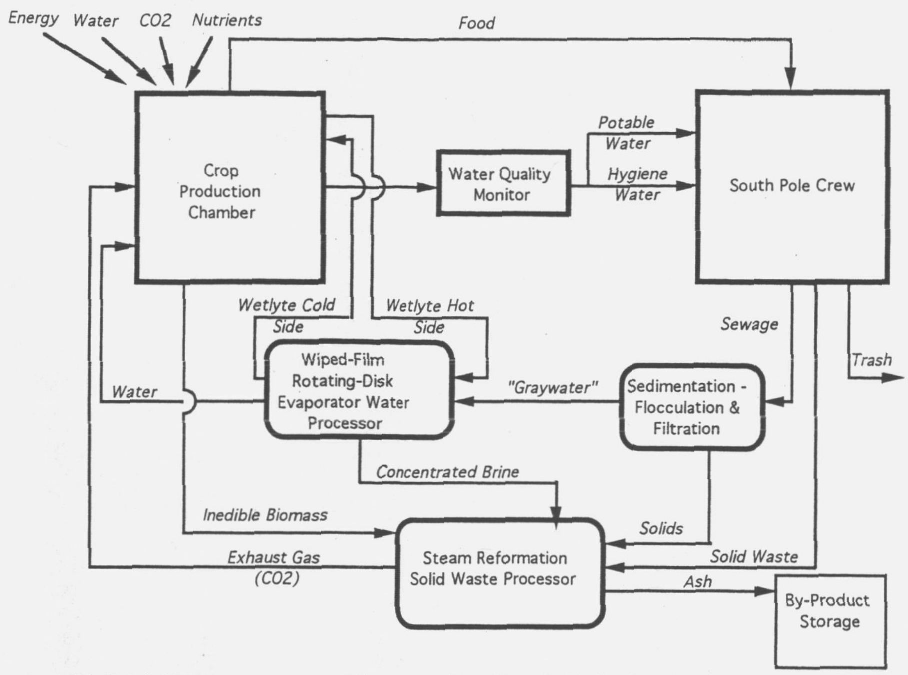


Figure 1 – NASA/NSF Mass Flow Diagram For South Pole Station
Power Systems Not Shown (Waste and Food Only)

Taken together this suite of technologies provides the capability for humans to live in extreme environments while minimizing their impact on the environment, maximizing reliability and safety, and reducing costs. The objective was to provide the capability to "leave no trace" of human occupation once the facility is decommissioned and removed.

This capability is unique and is a direct out growth of ongoing research conducted in support of NASA's mission to explore and colonize Mars while leaving no foot-print on the surface of Mars. For Antarctic applications this approach offers the additional benefit of significantly reducing operational costs by reducing or eliminating re-supply costs.

The NASA system was developed to the unique requirements of the NSF and the South pole Station. Its applicability to BAS is limited. However, the technology developed as a result of this program may be applicable to BAS and the construction of the Halley VI Research Station. The following sections provide a description of these technologies and two potential integration schemes that may be applied to the Halley VI Station.

Technology Descriptions

Polar Turbine

Designed specifically for extreme weather in remote science facilities, village power and distributed generation applications; the North Wind (NW)100 is a state of the art 100 kW maximum output utility-scale wind turbine.

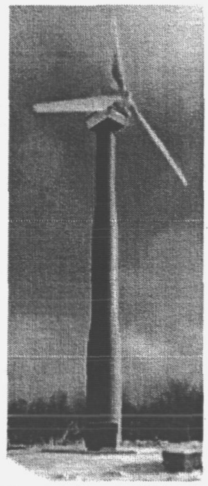


Figure 2 – NW 100

The design of the NW 100 has benefited from many years of operation of its smaller cousin the NW 3. The NW 3 has been operating at Black Island Antarctica since 1983. It operated at the South Pole during the 1995-96 season and has operated in more extreme conditions than any other turbines, including winds to 198 mph (88.5 m/s) and temperatures to -112°F (-80°C.) This experience gained in harsh, remote conditions has been incorporated into the NW100 design, affecting configuration, materials selection, performance characteristics, and deployment procedures. Designed to meet the needs of small utilities and independent power producers, in Artic and Antarctic applications the NW100 has the following features:

Simplicity
High reliability and low maintenance were the focus in developing the NW100. The design integrates industry proven robust components with innovative design features to maximize wind energy capture in severe and remote locations. The turbine features a minimum of moving parts and vulnerable subsystems to deliver high system availability. The uncomplicated direct drive rotor design allows safe, efficient turbine operation, and dramatically reduces maintenance requirements.

Serviceability
All service activities can occur within the tubular tower or nacelle housing, providing complete protection from severe weather conditions. Designated work areas provide ample room to perform service activities.

Power Quality
The most common generator utilized in the wind industry is a gear driven asynchronous (induction) generator. Induction generators must be connected to a stable voltage source for excitation and reactive power (VAR) support. While large power grids can easily provide this support, power quality and system stability is compromised in distributed generation and village systems where the power grid is typically "soft and unbalanced." The synchronous, variable speed

direct drive generator and integrated power converter increases energy capture, while eliminating current in-rush during control transitions. This turbine can be connected to large power grids and remote wind-diesel configurations without inducing surges, effectively providing grid support rather than compromising it.

System Description

The variable speed, stall controlled turbine rotor assembly consists of three fiberglass reinforced plastic (FRP) blades bolted to a rigid hub, which mounts directly to the generator shaft. This simple, robust design eliminates the need for rotating blade tips, blade pitch systems, and speed increasing gearboxes. Using a state-of-the-art airfoil design increases the blade's aerodynamic efficiency and renders them insensitive to surface roughness caused by dirt build-up and rind ice. The advanced FRP-resin infusion molding process ensures a high-quality blade while the root connection guarantees it will meet extreme temperature requirements.

The direct drive generator is a salient pole synchronous machine designed specifically for high reliability applications. Electrical output of the generator is converted to high quality AC power that can be synchronized to conventional or weak isolated grids. The advanced power conversion system also eliminates the inrush currents and poor power factor of conventional wind turbines. The output complies with IEEE 519-1992 power quality specifications. The variable speed direct drive generator/converter system is tuned to operate the rotor at the peak performance coefficient, and also allows stall point rotor control to contend with wide variation in air density found in many extreme target applications.

The safety system consists of a spring applied, pressure released disk brake mounted on the generator shaft for emergency conditions, and an electrodynamic brake system that provides both normal shutdown and emergency braking backup functions.

Wind Turbine Foundation

As part of the turbine development activity a new floating foundation was developed and tested. Figure 3 shows the foundation during a test of the NW 3 wind turbine at the South Pole in 1996. The test was successful and the approach is scalable to the NW 100 turbine.

Figure 3 – NW 100 Snow/Ice Foundation

Erection

The NW 100, complete with foundation, can be delivered in a ski equipped LC-130 aircraft or standard shipping container. The tower, nacelle, and turbine are self-erecting Via an internal to the tower crane system and can be assembled without a traditional crane on site.

Solid Waste

Steam Reforming is ideally suited for processing a wide range of organic wastes, including domestic, construction, RCRA/TSCA wastes, PCB wastes, and medical wastes. The Steam Reformers compact size, containment integrity, ability to treat wastes packaged in 55 gal drums, and steam-based chemistry offer significant safety and regulatory advantages over incineration and other thermal destruction systems. The technology vaporizes and destroys organics in either liquid or solid form, leaving behind a dry, non-hazardous, mineral-like solid residue contained in the drum. Wastes do not need to removed from the packing containers and can supplied in 55 gal drums, pumpable slurries or processed through a screw feeder system. Volume reductions of up to 100:1 are typical. The system offers destruction and removal efficiencies up to 99.9999%.

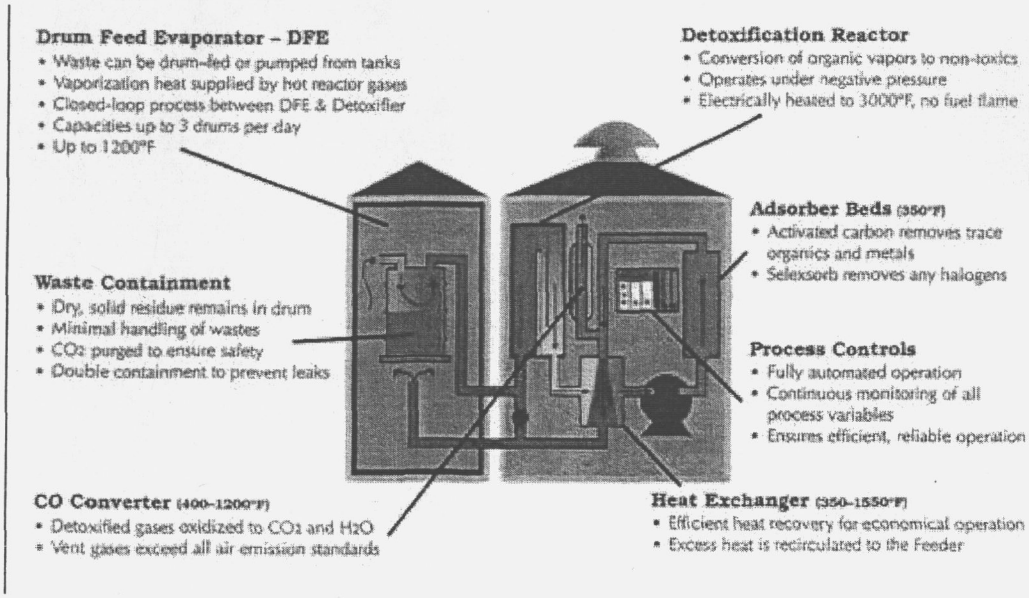


Figure 4 – Steam Reforming Process

Steam Reforming chemistry occurs in a steam-laden, oxygen-deficient environment to convert organic and biochemical compounds to CO, H2, CO2, N2 and H2O. This gas is considered a synthetic fuel and can be used for power generation, heating, or flared as a waste product. The two-step process first employs an evaporation phase, which breaks down and vaporizes the organics and water from the waste. Waste solids in the evaporator are not exposed to the a high enough temperature that hazardous metals and radionuclides will volatize from the residue.

Volatized gases exit the evaporator and pass through a filter, which removes any entrained particles. The particulate-free gas exiting the filter is then mixed with superheated steam and passed through a high-temperature reformer, where the organic vapors are fully destroyed. Since the process chemistry does not form the secondary pollutants and dioxins/furans associated with combustion, Steam Reforming is not classified as an incinerator by the U.S. Environmental Protection Agency (USEPA) and is easily licensed for on-site or fixed-based operations.

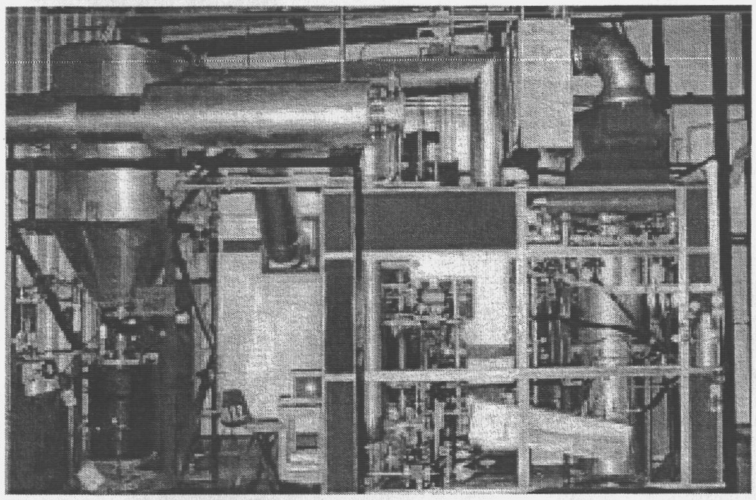


Figure 5 – Steam Reformer

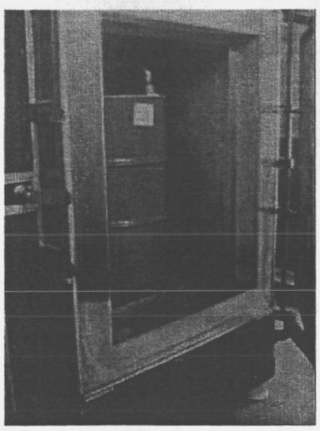


Figure 6 - Drum Feeder

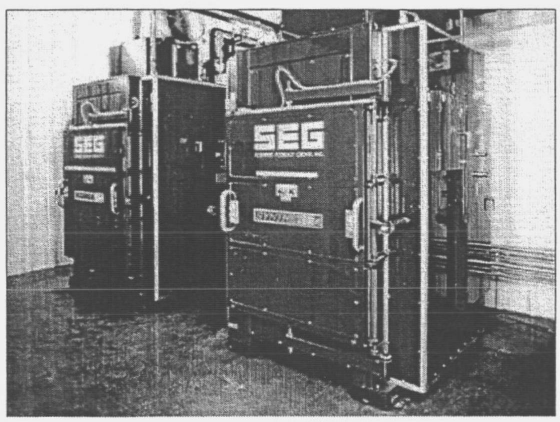


Figure 7 - Two Drum Feeder Configuration

Water Treatment System

The Water Reuse Technologies (WRT) Wiped-Film Rotating-Disk (WFRD) evaporator is a distillation based water purification technology. Figure 8 shows a 150 Kg/hr ground based system developed for recycling sewage at the South Pole Station. This technology is capable of operating as a conventional multi-effect vapor compression distillation processor or in a waste heat re-utilization configuration.

When operated in the waste heat re-utilization mode the vapor compressor is replaced by a waste heat generator such as the water jacket of a diesel generator or other source of low-grade waste heat. In the vapor compression distillation configuration the system runs on electricity or high pressure steam. The vapor compression distillation configuration is shown in Figure 8.

<u>WFRD Specifications</u>

- Production Rate: 150 Kg/hr Recovery Rate: > 97%
- Evaporator Heat Transfer Coefficient: 11-17 KW/m2C
- Specific Power Consumption (VCD Mode): 10-20 Whr/kg (electrical)
- Specific Power Consumption (MED Mode): ≈ 166 Whr/kg (thermal)

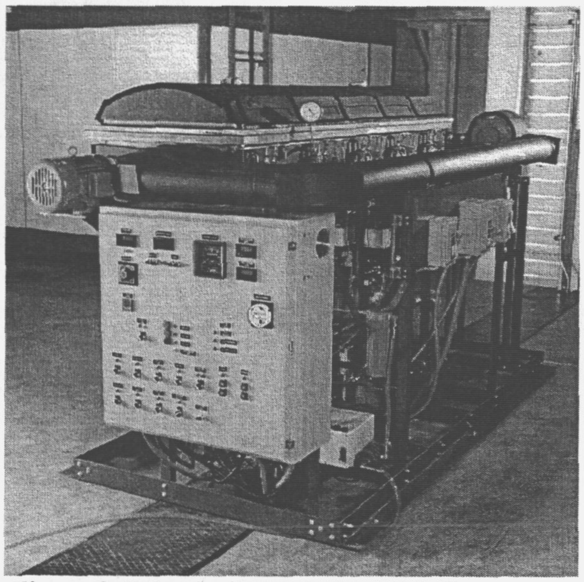


Figure 8: Wiped-Film Rotating-Disk Evaporator

Figure 9 shows how the WFRD vapor compression module works. The feed is first pre-heated and then enters the first effect of the evaporator. Here, part of the feed is evaporated and the balance is pumped from the first effect to the second effect. In the second effect part of the feed is evaporated and balance is pumped from the second effect to the third effect. This process is repeated until the fifth effect where the brine is taken out, cooled in the brine cooler, and discharged from the plant.

The vapor generated in the first effect flows in to the second effect and condenses on the cooler heat transfer surface there and is taken out as distillate. The heat released in condensing the vapor in the second effect is transferred across the heat transfer surface and causes evaporation of an equivalent amount of water from the feed in the second effect. This process is repeated in the third, fourth, and fifth effects to produce distillate streams from each effect. The vapor generated in the fifth effect is taken out, compressed to raise its saturation pressure and temperature, and then introduced to the condensing side of the first effect where it condenses on the heat transfer surface and then is withdrawn as distillate. The condensate streams from each of the five effects are combined, then cooled in the distillate cooler and taken out of the plant.

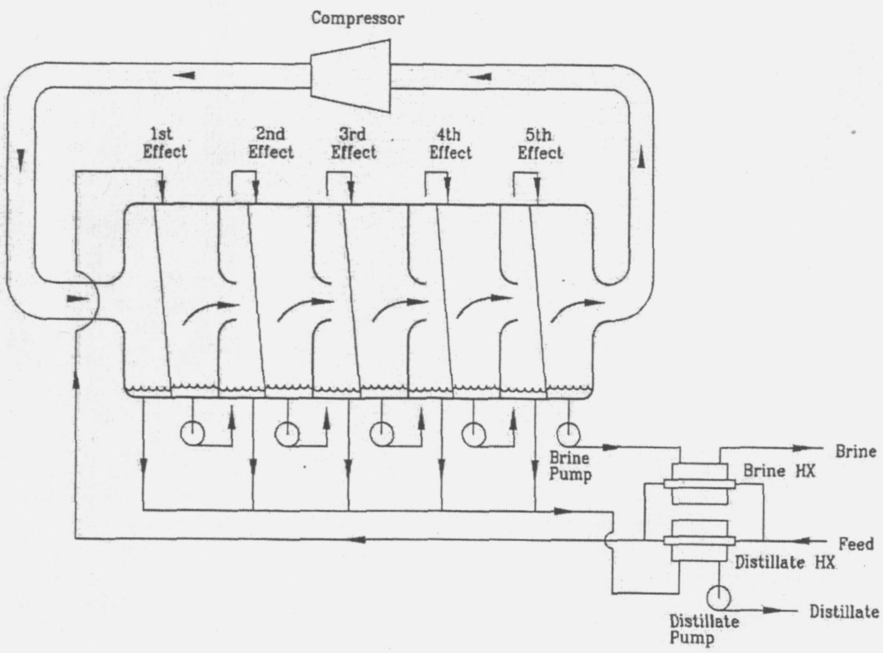


Figure 9 – WFRD Flow Diagram

The use of the WFRD in the Waste heat utilization mode is basically the same as in the vapor compression distillation process until the fifth effect is reached. The vapor from the fifth effect is removed and condensed in an external condenser, not compressed and returned to the first effect. The feed is used as the coolant.

The system uses a wiped-film rotating-disk design that allows it to operate with much higher solids loadings than competing systems. The system has demonstrated the ability to achieve 97% water recovery of black water (galley, toilet, shower, cloth wash, hygiene) returned from the South Pole Station.

Solids in the feed are successively concentrated as the brine moves into each effect. By the time it reaches the fifth effect solids loadings can easily be in excess of 20%. This brine is then pumped out of the system through the brine HX and discharged as a waste byproduct. The brine is typically 2% to 3% of the mass of the feed. If a Steam Reformer is available this brine can be dried to a stable ash. If not it would need to be transported and disposed of off site.

Performance evaluation of the WFRD was initiated during the 1996 fiscal year. Primary evaluations were conducted using South Pole Station wastewater collected during 1993/94 season. Results are provided in Table 1.

Table 1: Wiped Film Rotating Disk Performance

Parameter	South Pole Sewage	WFRD Distilled Product From South Pole Sewage Feed
Total Solids (ppm)	1462.4	ND
pH	7.3	8.5
Conductivity (umhos/cm)	831.8	140
Density (g/mL)	0.990	1.00
Ammonium	85.5	37
Calcium	58.9	<1
Chloride	75.8	<1
Copper	1.9	<0.001
Iron	0.4	<0.001
Lead	0.01	<0.001
Magnesium	17.1	<1
Nitrate	0.08	<1
Nitrite	1.17	<0.01
Phosphate	52.3	<1
Potassium	63	<1
Sodium	140.5	<1
Sulfate	33.3	<1
Total Phenols	N/A	<1
Total Organic Carbon (TOC)	517	36

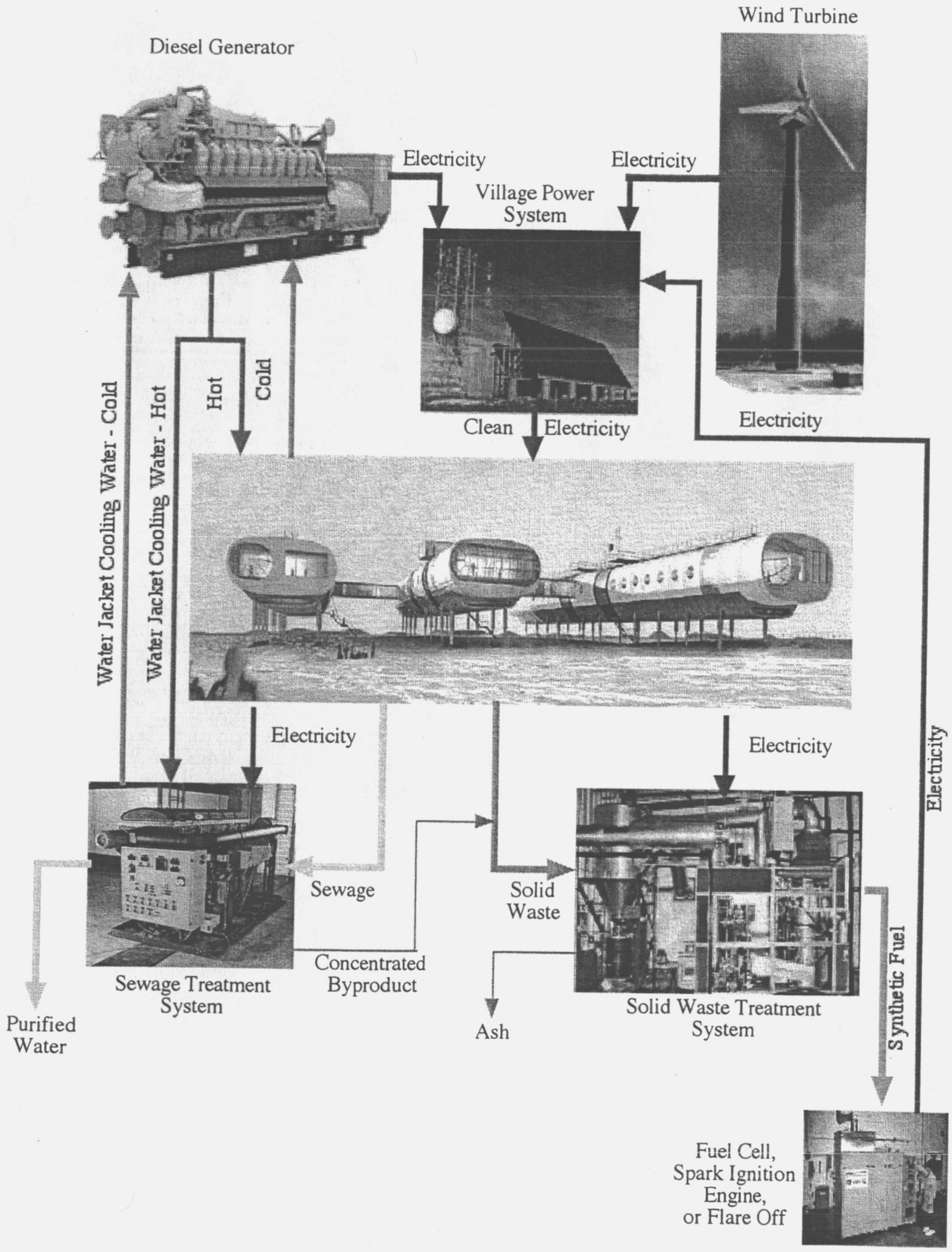
Integrated Configurations

Our group has over 12 years experience in the development of integrated power/waste systems in Aerospace Artic and Antarctic applications. Our terrestrial experience has shown that there are two approaches to implementing integrated system in facilities located in remote and harsh environments. The first is to fully integrate power and waste processing technologies with station infrastructure. This approach maximizes economic benefits. The second is to develop a stand-alone power waste processing system. This approach minimizes the risk of deploying advanced technology to the Antarctic.

Full integration with the station infrastructure means full integration with station power production. In the Antarctic power is life. System stability is critical. The variable nature of wind energy requires active control. Although the Village Power System provides the controls, power conditioning, and energy storage necessary to provide a stable intergraded power system, in many cases operators can be resistant to systems which have the potential to impact stability.

The stand-alone approach has the benefit that it can be implemented with no risk to power stability. The Village Power System can also be used to provide a stand-alone wind only power grid. Using this approach waste treatment is only provided when wind resources are available. Although this approach can be quite reliable, it does not offer the same economic benefit as a fully integrated system.

Fully Integrated Configuration



Stand Alone Configuration